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Totally Integrated Munitions Enterprise "Affordable Munitions Production for the 21st Century"

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Totally Integrated Munitions Enterprise (TIME)
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Abstract

The U.S. Army faces several munitions manufacturing issues: downsizing of the organic production base, timely fielding of affordable smart munitions, and munitions replenishment during national emergencies. TIME is addressing these complex issues via the development and demonstration of an integrated enterprise. The enterprise will include the tools, network, and open modular architecture controller to enable accelerated acquisition, shortened concept to volume production, lower life cycle costs, capture of critical manufacturing processes, and communication of process parameters between remote sites to rapidly spin-off production for replenishment by commercial sources. TIME addresses the enterprise as a system, integrating design, engineering, manufacturing, administration, and logistics.

Background

TACOM-ARDEC was introduced to the concept of the Totally Integrated Manufacturing Enterprise (TIME) in 1996. During that timeframe the ammunition industrial base was experiencing significant downsizing. There was not and most likely would no longer be sizeable procurement contracts. The Army Owned Ammunition Plants were all producing at a fraction of their capacities. The privately owned base was struggling also. Large numbers of producers were leaving the business. Also, development of new items especially new energetic formulations, was taking roughly 10 years or more from the time of feasibility demonstration to time of production.

The TIME concept, if it could be successfully developed and implemented, was seen as the answer to both of these issues. It would significantly shorten the time from concept inception to full production and it would also result in a base configured to link pilot capability to production capability and allow rapid transfer of technology and information from development site to production site or sites. Therefore, with the support of the Office of Munitions in the Office of the Secretary of Defense the TIME project was initiated in 1997 with Congressionally directed funds.

The Vision

The TIME program will develop and demonstrate a **T**otally **I**ntegrated **M**unitions **E**nterprise. It is designed to provide the Department of Defense (DoD) with a cost-effective, rapidly reconfigurable, distributed, and flexible manufacturing capability configured to meet munitions needs in the 21st century. The existing production base for munitions is not agile and is not fully capable of producing next generation munitions without significant investment. Additionally, utilization of these existing facilities is extremely low, contributing to high product costs. Initially focused on munitions the architecture and concepts being developed can support a more generic virtual manufacturing enterprise.

Based on the TIME concept, TACOM-ARDEC has formulated a production base plan that envisions a very different paradigm. The base is really an enterprise; it entails coupling design to prototyping to low rate production and to expanded production. This concept could at some point expand to consider storage, maintenance, resupply and demilitarization aspects. But initially, the enterprise will comprise all entities involved in design through production, fully integrated and able to utilize tools and data in a fully functioning communications infrastructure.

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The ultimate enterprise would utilize physics based models to control key manufacturing operations. Management would have access and input to these operations and their resultant costs. Item design would consider life cycle aspects especially through modeling and simulation of processes. Models to machine instructions, able to be executed at various production sites, would convert designs. All enterprise elements are nodes on the network able to interface to the maximum degree necessary.

This seems far-fetched especially when one considers the state of the ammunition base today. However, capabilities to allow this vision to become real are being developed and demonstrated in a phased plan under the TIME program.

The Operating Philosophy

TIME is working to provide an infrastructure for concurrent engineering and other munitions enterprise management functions. Development and integration activities will provide a munitions manufacturing enterprise with its associated communications network. Demonstration projects in materials, processes, and selected munitions are also included in the program to demonstrate long-term savings in dollars and time. Concurrent engineering, integrated product and process development, and agile manufacturing are the major themes throughout this initiative.

Seamless interaction via a ubiquitous communication network within the enterprise will enable rapid response to product and engineering changes. DoD design, testing, and engineering facilities will be able to route manufacturing specifications and procedures directly to various parts of the enterprise, thereby achieving maximum flexibility in production scheduling and optimum control of the prototyping and production processes.

TIME will allow use of commercial facilities to ramp up munitions production in times of national emergency. This will be accomplished by applying agile manufacturing techniques such as electronic sharing of feature-based product and process models and information, design of agile manufacturing cells using commercial equipment controlled by open modular architecture controllers (OMACs), use of commercially viable standards, and the creation of virtual enterprises that facilitate the teaming of private companies. The use of OMACs drives the virtual enterprise down to the shop floor in a more comprehensive and useful way then currently achieved.

The Lawrence Livermore National Laboratory is one of eight participants in the TIME project. Most other participants, including Raytheon, General Motors Powertrain, Extrude Hone, Aerojet, and Primex, are in the private sector. Together, project participants are developing and demonstrating a distributed, flexible manufacturing capability that is cost-effective and can be rapidly reconfigured as needs change.

The Virtual Distributed Enterprise

TIME defines a suite of technology tasks and a technical strategy that will provide significant near-term and long-term benefits to the defense-manufacturing sector. The foundation of the program is a vision of a virtual, distributed enterprise in an agile environment where organizations can swiftly and cost-effectively bring products from design to production and respond dynamically to changes in product requirements. Attributes of the agile enterprise include the ability to:

- rapidly transition products from design to production in a single iteration, cutting time to market and responding to market needs;
- rapidly integrate virtual enterprises where manufacturers and suppliers operate as a unified entity unconstrained by geographic separation;
- seamlessly communicate requirements, plans, designs, models, metrics, results, and other vital data to and from stakeholders in the product realization process;
- allocate production between facilities, transmit and receive production data and exchange information with contractors on an ongoing basis;
- encourage interaction between product team members, creating teamwork and more timely feedback resulting in higher quality products; and
- incorporate business functions that drive the manufacturing requirements, operations, and post-production activities of product distribution and support.

The Product Realization Model

The product realization process (Figure 1) is driven by needs input from the customer and supplier stakeholders to provide solutions. The collection of enterprise knowledge captured from past experiences that includes data, information, and domain knowledge for products, manufacturing processes, and enterprise resources is referred to as a script. This process is based on development and execution of a product realization script managed in a concurrent environment. The script is optimized for performance and value by trading off critical parameters in the product, process, and resource domains during the composition phase, where stakeholders access and influence the development of the script. The script is realized during the execution phase, where acquisition, fabrication, and assembly are conducted to produce deliverable products. The script is based on enterprise knowledge captured from past experiences and includes data, information, and domain knowledge for products, manufacturing processes, and enterprise resources. Each of these knowledge bases is integrated through an open-architecture infrastructure that enables team collaboration, interoperability, and portability of tools.

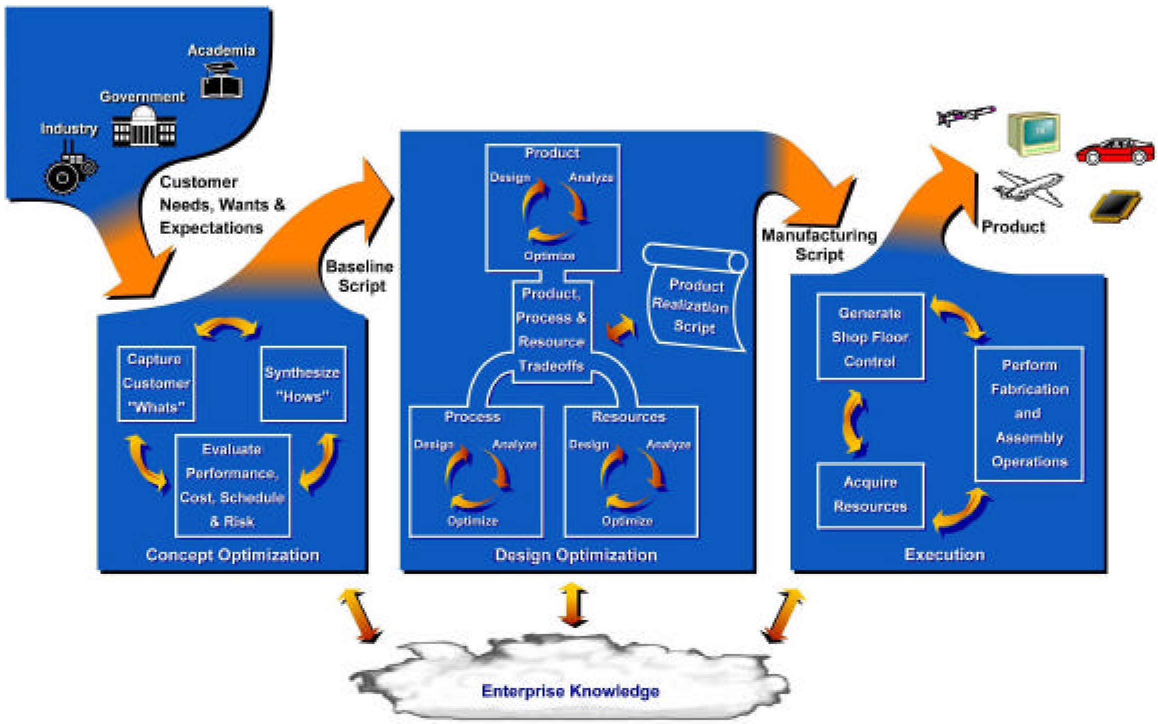

Figure 1: Product Realization Model utilized by TIME

Architecture

The TIME architecture is being described in a living document that captures the vision for the entire enterprise and provides a basis for multi-year planning as TIME continues to evolve. This document captures the high level architecture envisioned under the TIME program. The definition of this architecture allows implementation of processes that facilitate the use of world-class, emergent, and existing tools to improve product/process integration and provide a technically sound basis for timely development of robust products, their life cycle management, and integration with other enterprise systems.

The Toolset of Enabling Technologies

TIME will procure/develop, validate, and deploy technologies that enable an information-driven, agile manufacturing base. Capabilities will be realized using commercial off-the-shelf products to the greatest extent possible. Figure 2 illustrates the breadth of tools required to support the product realization process. In order to make the virtual, distributed enterprise, integration technologies are used to facilitate the seamless integration of the tools.

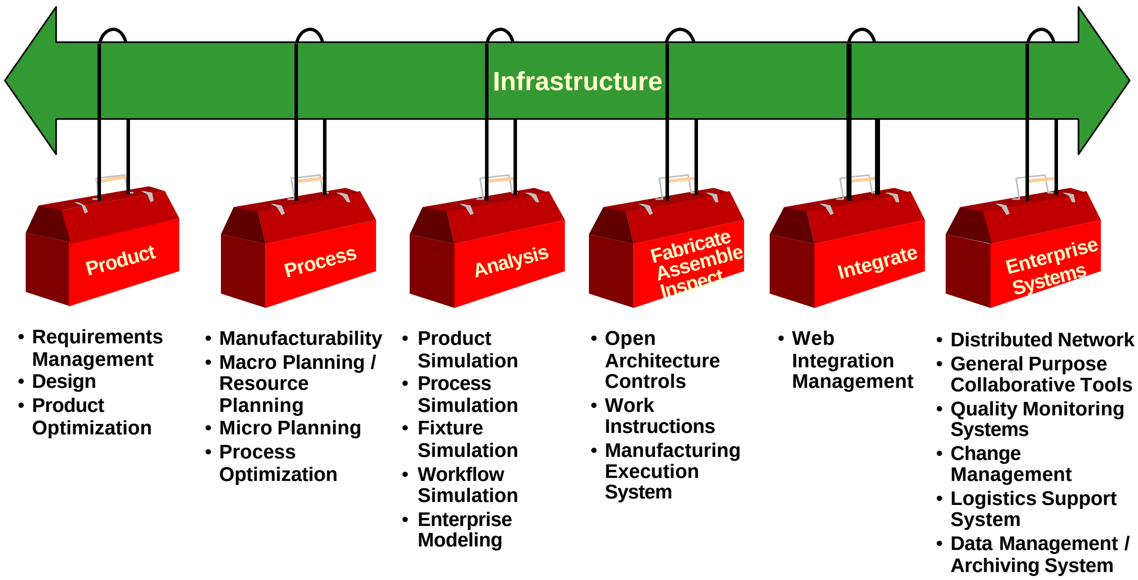

Figure 2: The breath of tools required for integration into the virtual enterprise

TIME accomplishes many of its goals through a phased set of technology integration, validation, demonstration, and development activities. These technology activities are done within the framework of the TIME architecture. Currently funded efforts are discussed below.

This figure also depicts the integrated infrastructure of tools, which TIME is assembling. TIME will not develop all of these tools but will utilize off the shelf models to the maximum degree. TIME has developed an architecture for this toolset, which will be adjusted as learning occurs through each progressively difficult demonstration.

Product Realization

Product realization is the conversion of customer requirements into delivered products. The product realization concept operates on the premise that once customer needs are established to the point that product requirements can be discretely defined, the producibility, process modeling, simulation, analysis, and resource planning functions interoperate seamlessly and concurrently to provide accurate assessments of cost, performance, and schedule for conceptual product realization approaches. This seamlessness and concurrency enable the enterprise and the customer to rapidly evaluate tradeoffs of key factors to arrive at an optimized, validated design for the product and its supporting processes.

To support this fundamental change, TIME addresses the entire process as a system, integrating design, engineering, manufacturing, administration, and logistics. To facilitate the flow of information among various functions, TIME is making use of a host of Internet-based software tools. Many of these tools were developed during an earlier U.S. Department of Energy (DOE) project known as Technologies Enabling Agile Manufacturing (TEAM).

These Internet-based software tools support not only an open flow of information, but also modeling of all phases of the work, communication among computing systems for geographically distributed facilities, concurrent engineering and production for teams that may be using different standards, and state-of-the-art methods for controlling manufacturing processes. A "web integration manager" pulls together all functions, including product design, process planning, process simulation, and fabrication controls. Figure 3 shows the non-expert transparently using one of the "web integration manager" tools to modify a design, run cost and product simulations, and finally run a tradeoff study.

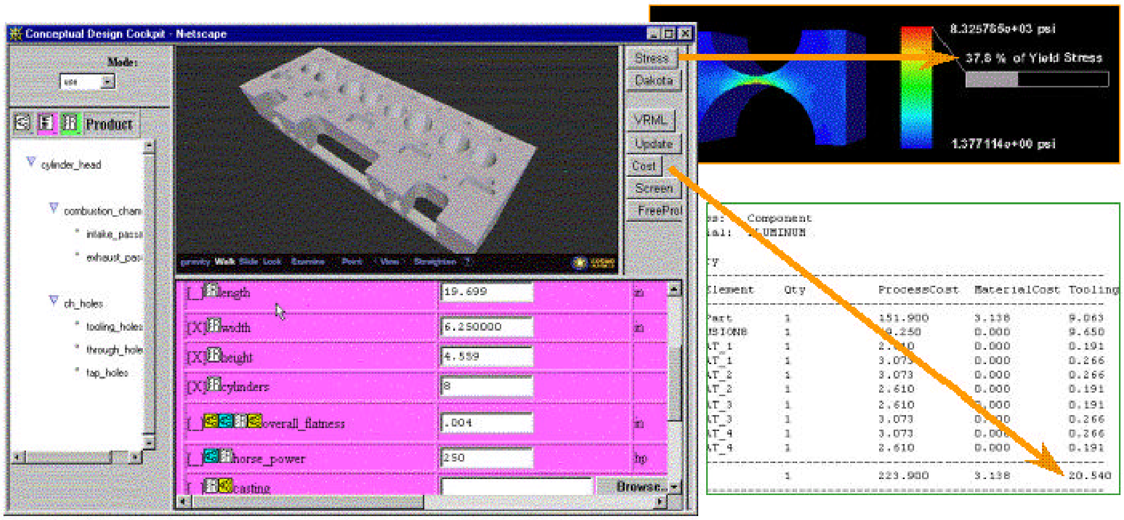

Figure 3: The Concept Design Cockpit for conceptual design studies

As important as these software tools were other activities to support a generic infrastructure and overall planning and management. These integrative elements are what make the TIME project possible today.

Manufacturing facilities of TEAM partners served as the proving ground for these models and software tools. The Internet-based tools allowed a large number of facilities to work together quickly and easily. In one instance, project requirements were analyzed at GM in Pontiac; design was done collaboratively between a DOE site in Kansas City and Raytheon in Tucson; the product analysis was performed at Livermore and ISX in Atlanta, DOE sites in Oak Ridge and Kansas City completed process design, and process simulation was performed by the University of Illinois and a DOE site in Los Alamo. Tradeoff studies between product, process, and resources were performed wherever the product manager happened to be. Then parts were manufactured at GM in Pontiac and inspected at Ford in Dearborn.

The real payoff for bringing together these Internet-based tools is in the way they enabled real change. What happens if a machine that is supposed to manufacture a part is down for maintenance, and the only other available machine isn't as accurate? But to use this other machine the entire process design, process simulation, and tradeoff studies must be done over again. The TEAM project demonstrated precisely this scenario but across 10 different facilities, making the changeover in less than an hour instead of days or even weeks.

TIME is leveraging this work done by the DOE TEAM program to develop an initial product realization environment for mechanical piece parts. The toolset for mechanical piece part product realization is assembled from commercial off the shelf (COTS) products integrated together with the TEAM developed and TIME modified internet-based software tools. The initial toolset being deployed for mechanical piece parts is shown in Figure 4 and will be available to TIME partners in the summer of 2000.

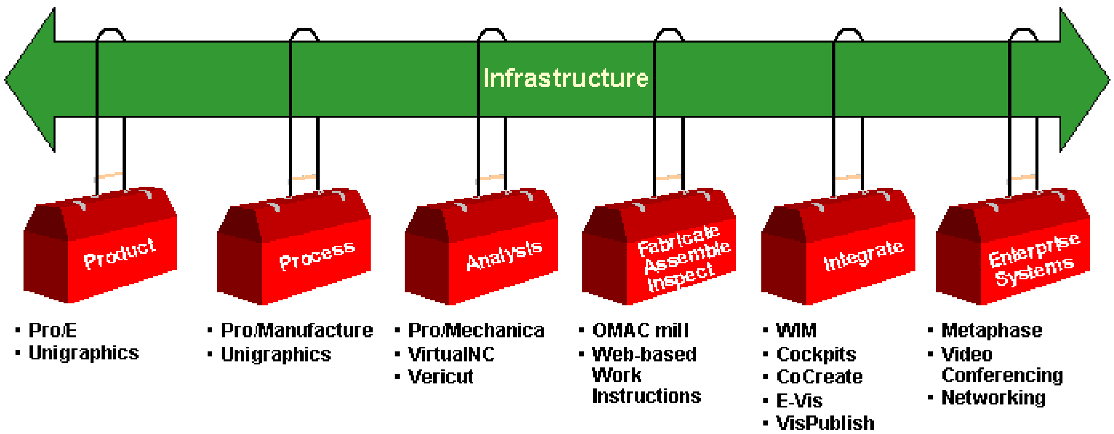

Figure 4: Initial toolset for mechanical piece part product realization

Although initially focused on mechanical piece parts, TIME is also pursuing work in electronic assemblies, composites, explosives, and metal forming.

Open Modular Architecture Controllers

The goal of an open architecture controller is to create an environment, which allows the largest variety of control problems to be solved over a wide range of performance and price. It is NOT to create a single controller, which will be able to solve every possible problem. Rather it is to create a controller architecture, which is sufficiently flexible and scalable, so that reasonable tradeoffs between performance, price, and flexibility may be made by the end user. TIME in cooperation with over 200 companies is developing this controller architecture.

This effort began in 1994 with the publication of the Requirements of Open, Modular Architecture Controllers for Applications in the Automotive Industry document. This was a document put together by the automotive industry describing their needs in the area of controllers. In an effort to promote these open architecture control solutions the Open Modular Architecture Controller (OMAC) Users Group was formed by the automotive companies and about 10 other large end users. This group has grown to over 200 (e.g. Allen-Bradley, Boeing, Bosh, Caterpillar, Cummins Engine, Daimler Chrysler, Deere, Delta Tau, Eastman Kodak, Ford, GE Fanuc, General Dynamics, General Mills, General Motors, Goodyear, Indramat, Ingersoll, Makino, Mazak, MDSI, Microsoft, Monarch, Okuma, Pratt & Whitney, Siemens, STEP Tools, VenturCom, Vickers Electronic Systems, Wind River, etc), including fifty Fortune 200 companies.

The structure of the OMAC Users Group includes companies with interests in developing and implementing open control technologies for manufacturing applications. Open control technologies of interest include applying the Windows NT operating system with hard real time extensions in manufacturing and common application programming interface (API) for motion and machining operations plus many others. One of the key objectives of the OMAC Users Group is to accelerate the availability of OMAC-based products that end users can purchase and implement in their manufacturing facilities.

A working group of OMAC was formed to develop a specification that defines an intelligent closed loop controller environment to support open architecture concepts including application portability at the source level, interoperability of modules, and extensibility of controller functionality. It is intended for system integrators and applications software developers to specify standard APIs for an open architecture controller and will be released in 2000. This working group used the requirements and initial API definitions from the DOE TEAM program as the basis for their work.

In defining this architecture, one of the overriding requirements was allowing one component to be swapped with another component. In other words allowing one implementation of a module to be replaced with another implementation. This required that the APIs specify how the results of a computation are accessed, but not how the calculation is carried out.

The original OMAC requirements specified that the controller be open, modular, and scaleable. The openness and modularity requirements were addressed by breaking the controller into several replaceable pieces, defining the state behavior for those pieces, and specifying their APIs. Scalability, which was defined as “enabling easy and efficient reconfiguration to meet specific application needs, from low to high end”, has several dimensions to it. One of these is the ability to extend the APIs of the modules (for more demanding, unanticipated needs), while still allowing backwards compatibility with existing components. This was addressed by treating the module APIs as objected oriented entities, which had no implementation. Inheritance is used to extend any given API, and therefore any given module. A software component, for purposes of OMAC, is required to implement one, or more, well defined API sets, have a well-defined state behavior (which is reflected in the individual API sets), and be easily integrated into a controller or exchanged with another compatible component. Ideally these components could be shipped as binary code, rather than source code, allowing software producers to protect their proprietary knowledge. Figure 5 is a graphical illustration of these concepts.

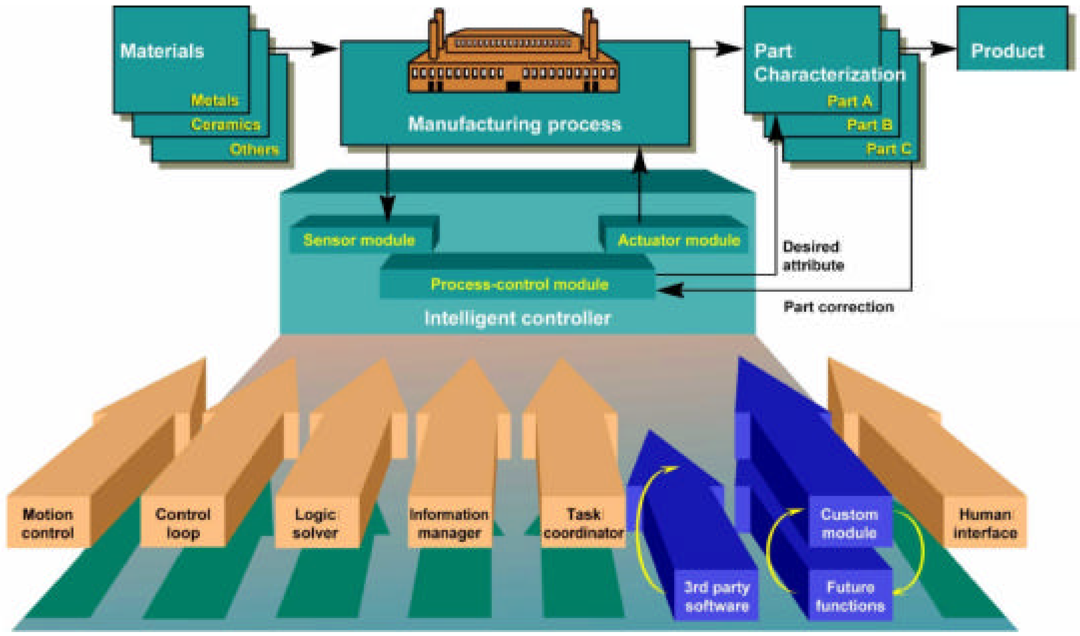

Figure 5: OMAC with standardized Applications Programming Interfaces

But the APIs are only a document until a reference implementation is built that proves that they work. This reference implementation is a controller built upon the OMAC defined APIs and available to controller vendors as a starting point for their own commercialized implementations. TIME has implemented a reference implementation of an extensible machine tool controller using Java. This controller is based on well-defined OMAC module APIs and component APIs. In addition, TIME has implemented rudimentary integration tools that take advantage of the component APIs, generating application code and checking for system consistency. Different test configurations of this controller will be released in the spring of 2000.

Enterprise Systems

Enterprise planning and management is essential to capture the implementation vision for the entire enterprise phased over a multi-year period as TIME continues to evolve. This effort includes life cycle management, and review of plans for support of logistics and repair functions and other supply chain functions. This effort will provide an assessment and generate requirements for TACOM-ARDEC and its ammunition makers in order to deploy business and manufacturing systems that will allow realization of the envisioned virtual munitions manufacturing enterprise. Integration of an initial set of enterprise tools will be accomplished and detailed planning for both initial deployment and continuous improvement of these systems will be done.

Demonstrations

Integral and concurrent to development of all facets of TIME is proof-of-principle demonstrations outside the laboratory. The capability to seamlessly communicate and transfer processes between sites, and remote site operation shall be demonstrated (Figure 6).

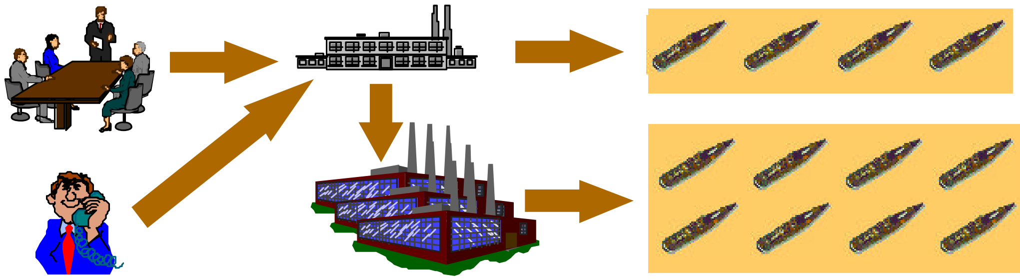

Figure 6: Demonstrations will validate the virtual enterprise concepts including the ability to leverage commercial facilities for surge capacities

Several manufacturing technology development efforts are being executed in conjunction with the TIME Program in the areas of metal parts manufacture, propellant and explosives manufacture, and composite parts fabrication. Metal parts manufacture using a milling machine as well as propellants manufacture using a twin-screw mixer/extruder has been demonstrated. Additional demonstrations will build upon these efforts to demonstrate the transfer of design and production process information in an accurate and reproducible manner. The end result will be a demonstrated ability to utilize non-traditional production capabilities to satisfy munitions requirements.

As each portion of the architecture and it's related tools are completed, a trial is conducted. To date, two such demos have been performed. The first involved electronically forwarding a novel explosively formed penetrator design, CAD data, from ARDEC to Aerojet in California. Aerojet in turn forwarded the CAM data to Lawrence Livermore National Laboratory (LLNL) where it was machined on a mill controlled by an OMAC developed by LLNL. OMAC is a key requirement of this enterprise. The second demonstration involved ARDEC sending a mortar design to Scranton Army Ammunition Plant. Scranton converted the design the CAM data and machined the part. In turn that CAM data was provided to General Motors Powertrain who in turn machined the identical part.

Two additional demonstrations are funded. The first will involve a validation of the OMAC for the mill. This validation will be directed at verification that the OMAC is fully capable of doing everything an off the shelf controller would do. This is a significant effort, the start of a series of efforts to commercialize the entire OMAC approach. These efforts should result in the software and control industry recognizing the capability of the TIME OMAC and its utility in the marketplace. The second effort will involve a metal part grenade body being manufactured at PRIMEX in Downey, CA., and all operations electronically transferred and then duplicated by General Motors. With the completion of these demos the concept of utilizing existing metal part producers and transferring their metal removal operations to a commercial site will be completed. The concept of using commercial non-defense producers for expansion of capability for replenishment purposes will have been demonstrated.

A further effort that is being considered for 2001 funding, if Congress provides such funds, is a demonstration of model based control using open architecture controllers. The twin-screw extruder TIME network will be modified to incorporate the OMAC.

This effort's purpose is to demonstrate the ability to control the extrusion and mixing of energetic formulations through sensor feedback to a mathematical model and automatic adjustment by the control system of key parameters. This demonstration is fundamental to proof of the base concept and essential prior to implementation of the model based control approach on any line.

Presently, a design project is proceeding taking this concept of model-based control and applying it to a melt pour production line at Iowa Army Ammunition Plant. The control system, including open architecture control will be described in depth in what follows including the justification for the need for OMAC in this TIME program approach. Following completion of this design and the completion of the twin-screw extruder OMAC demo, a project to execute the melt pour design as a prototype project funded through Production Base Support funding is anticipated.

Independent Analysis of TIME

TIME address real needs and is on track to deliver solutions. This has been validated by independent evaluations that have continuously supported TIME and have suggested its adoption by the Army as a means to meet their requirements in the 21st century.

The DOE requires an annual review of the programs within its national laboratories. Therefore independent advisory committees have reviewed the TIME program on three separate occasions. Members of these committees have come from the Office of the President of the University of California (the operator of the Lawrence Livermore National Laboratory), Argonne National Laboratory, Battelle, Bechtel, Boeing, Council on Competitiveness, ETT Development, General Electric, National Renewable Energy Lab, National Science Foundation, Polytechnic University, Southwest Research Institute, Texas A&M, and Westinghouse. In every case the project has received an excellent rating in all areas of the program, especially the OMAC work. The review conducted in the spring of 2000 included comments such as "manufacturing is outstanding in developing machine independent controllers". Comments such as "fit architecture into design/build cycle" validated our efforts to move the OMAC component based architecture into the enterprise.

The National Center for Advanced Technologies was tasked with performing a study for the Army. This study was to provide an industry view of the Army's strategy, plans & approach to gun-launched munitions; identify & address technology, industry, and business challenges; and provide an improved munitions strategy & approach for civil-military integration. As part of that effort the TIME program was investigated for its applicability to meeting the Army's needs. A specific recommendation of the study was to utilize the TIME information technologies to reduce development lead-time. It was also recommended to utilize TIME to streamline, consolidate, & modernize the industrial base.

Summary

TIME has been designed to address the challenges faced by the U.S. Army munitions manufacturing base. The virtual enterprise provides a high degree of flexibility and reconfigurability that not only benefits the existing munitions base but also allows effective utilization of commercial facilities to produce munitions in times of national emergencies. TIME is being developed through a phased program aimed at leveraging commercial off-the-shelf tools, providing critical enabling technologies, and a robust infrastructure supporting manufacturing. Systems, networks, and tools are important elements of the enterprise. Robust core functionality initially focused on material removal but extensible to assemblies, electronics, composites, and other modalities provide another key component for TIME. Throughout the program, TIME will validate the effectiveness and ruggedness of the processes and technologies through demonstrations and pilots before rolling out to larger efforts. Successful development and implementation of the technologies necessary to establish a virtual manufacturing enterprise for munitions production will enable DoD to reduce infrastructure and end item costs while shortening design to fielding times and enabling rapid replenishment to meet both peacetime and emergency needs.